Control of the condition of heat exchange surfaces by free vibration method

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Control of the condition of heat exchange surfaces by free vibration method

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Abstract. In power system the main heat carrier is the fresh water received from natural sources, and containing a large amount of various impurity – from the dissolved mineral salts to organic compounds. In housing and communal services and the industry cases of operation of heat-exchange devices and package boilers without special preparation of water aren't rare. During the operation of the heat-exchange equipment of impurity are allocated in a firm phase both in the form of deposits and in the form of slime. Sediments cause deterioration in a heat transfer that leads to decrease in overall performance of the equipment (to an excessive consumption of fuel, metal overheating, etc.). The radiation surfaces of modern steam generators heating are intensively warmed with a furnace torch. Density of a thermal stream in them reaches 600-700 kW/sq.m, and local thermal streams can be even higher. Therefore even short-term deterioration in coefficient of a thermolysis from a wall to the boiling water leads to significant increase in temperature of a wall of a pipe (500-600 °C and above), durability of metal can it is insufficient to sustain tension which has arisen in him. The metal damages which are characterized by emergence of blisters, fistulas are a consequence of it, and it is frequent also a rupture of pipes. The scum reduces the useful section of pipes, increasing the hydraulic resistance of pipes of the heat exchanger. Everything together it involves an excessive consumption of fuel, and according to expert data the layer of scale up to 0.2 mm thick increases fuel consumption by 3%, and a layer in 1 mm for 7%.

The serious problem of fight against sediments arises in heat exchangers of hot water supply when the section of pipes through passage and the surfaces of heat exchange almost completely grows with sediments. Overgrowing by sediments of thermal systems pipelines including reverse water supply, leads to significant increase in their hydraulic resistance, maladjustment of heating systems and big power losses by pumping of system.

There is a similar situation with power losses from sediments in air conditioning systems (table 1).

Tab. 1. Losses from sediments in air conditioning systems depending on thickness of a sediments layer

Thickness of a sediment layer (mm)	0.5	1	2	4	6	8	10	12.7
Deceleration of power of the conditioner (%)	5	9	17	23	29	34	50	56
Increase of temperature at the exit from the evaporator (°C)	0.4	0.8	1.6	3.2	4.8	6.4	8	10
Electric power overexpenditure (%)	5.8	10.6	20.2	29.4	35.6	46.8	66	76

It is possible to reduce energetic losses by timely cleaning of internal surfaces from scale and sediments. For this purpose it is necessary to have a reliable, available technique and the equipment

for monitoring of sediments thickness.

For monitoring of sediments thickness on heat-exchanging surfaces it is offered to use the method of the free oscillations [1] consisting with following. In case of shock on a surface of a controlled product in it there are mechanical oscillations which will be transformed to an electrical signal by the sensor, register, spectrum analysis is carried out them [2]. Existence of sediments changes thickness, mass of heat exchange surfaces, therefore, and natural frequencies of oscillations. Having "the acoustic passport" of a new product, knowing the current oscillation frequencies of controlled surfaces it is possible to determine thickness of sediments [3].

With use of the software package of "ANSYS" [4] simulation of oscillation frequencies of the metal plate of 2 mm thickness, jammed on perimeter without precipitate and with the different thickness of sediments (0.1, 0.3, 0.7, 1, 1.5, 2.0, 3.0 mm) is carried out.

Results of frequencies calculations of natural oscillations of plates are provided in the table. 2.

Tab. 2. Results of plate measurements with different thickness of sediments

Type of a plate	clean plate	plate with a layer of 0.1 mm	plate with a layer of 0.3 mm	plate with a layer of 0.7 mm	plate with a layer of 1 mm	plate with a layer of 1.5 mm	plate with a layer of 2 mm	plate with a layer of 3 mm
Number of fluctuations form	Frequency of fluctuations [Hz]							
1	1076	1081	1096	1152	1216	1355	1526	1927
2	2002	2012	2045	2160	2284	2551	2870	3586
3	2958	2971	3013	3165	3336	3709	4164	5202
4	4431	4453	4522	4767	5033	5603	6281	7781
5	5790	5813	5894	6186	6511	7216	8062	9941
6	7542	7576	7689	8088	8525	9453	10545	11063
7	7641	7672	7778	8164	8594	9526	10647	12910
8	9542	9579	9707	10177	10697	11426	11293	13154
9	10006	10048	10190	10699	11257	11810	13121	15944
10	11440	11489	11652	11672	11574	12445	13841	16862

The analysis of the received results shows that even existence of a precipitate 0.1 mm thick leads to change of the first oscillation frequency of model on 5 Hz, and the 9th and 10th forms of oscillations on 42 and 49 Hz. Such shift of frequencies in the sound range can be determined by the spectrum analyzer of oscillations using an algorithm of the fast Fourier transform [5].

For conducting the pilot studies of influence of sediments thickness on oscillation frequencies the laboratory bench which schematic block diagram and photo is provided in fig. 1, 2 is created.

The stand consists of the registration system and processing system of signals. The device of the researched plate fixing is a part of the registration system. Excitation of plate oscillations is carried out by the mechanical drummer of pendulum type. The persistence of shock force is provided with assignment of the pendulum on the same angle. After excitation of product oscillations the analog signal from sensors of oscillations comes to the personal computer (PC) on an input of the analog-to-digital converter (ATDC). The received digital signal registers in the form of the file in a hard drive of the computer, and then is exposed to later processing.

As the sensor of oscillations in this complex the microphone is used.

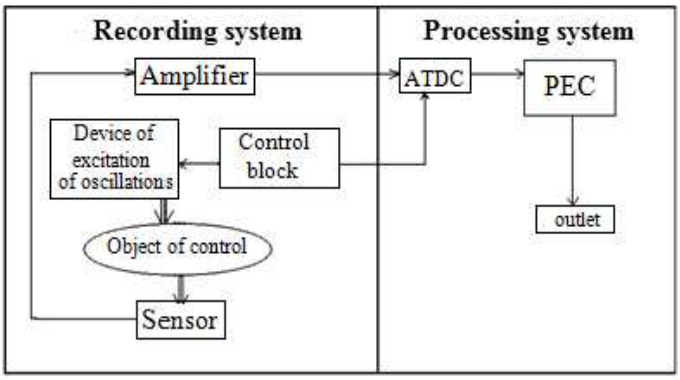

Fig. 1. Block scheme of the stand

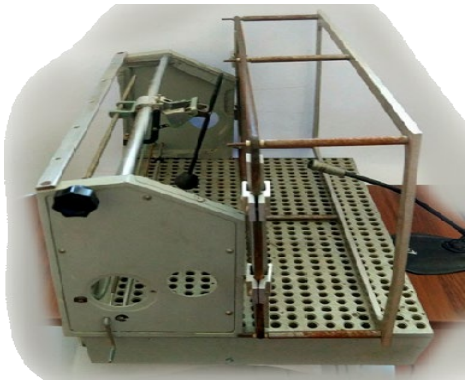

Fig. 2. Photo of an experimental complex for a research of fluctuations at different layers of sediments, a side view

As model of a surface of the heat-exchanging equipment the steel plate 400 mm long, 160 mm wide and 2 mm thick was used.

In case of a research of acoustic characteristics with each type of a plate tenfold determination of frequencies of natural oscillations of a plate was carried out. Blow was struck to a plate, and measurement of amplitude-frequency characteristics of a response was taken by the microphone which is in break point.

After a series of experiments the layer of sediments was applied on a plate and researches repeated. Ranges of oscillations of a pure plate and plate with sediments 0.5 mm thick are provided in fig. 3.

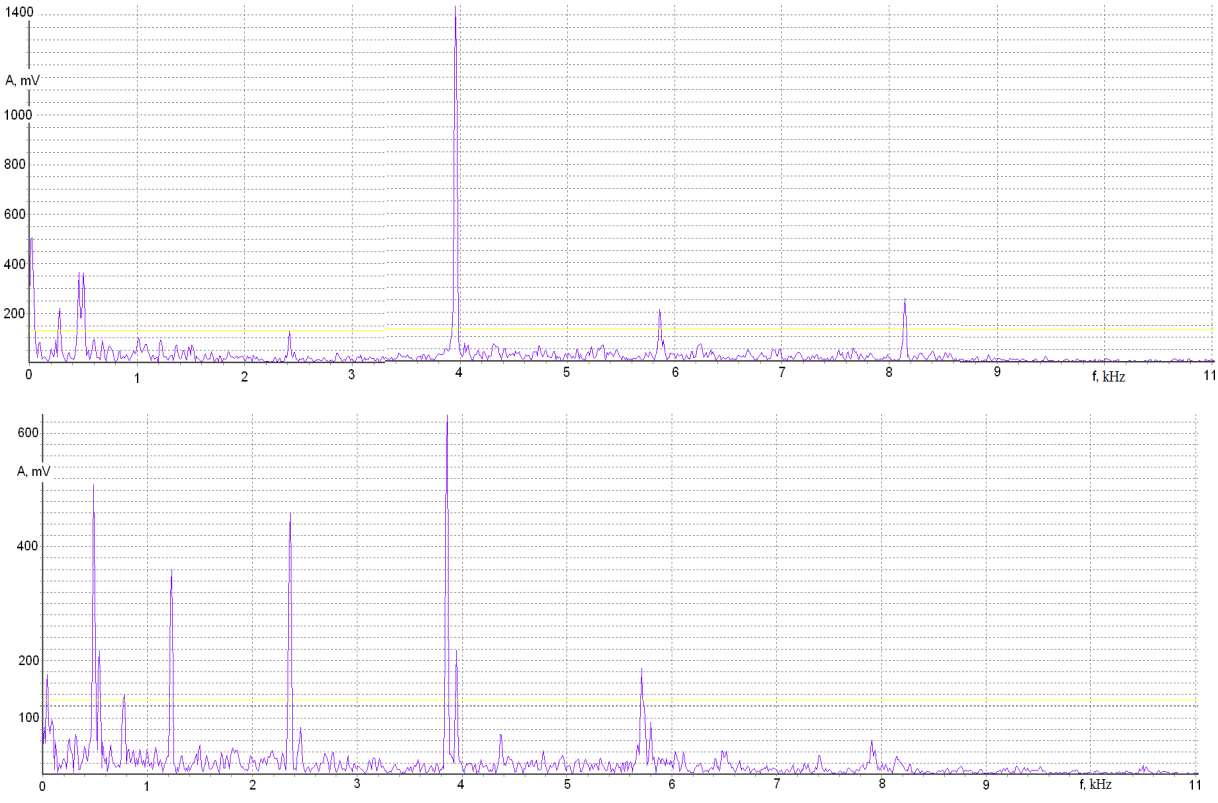

Fig. 3. Ranges of fluctuations of a clean plate (top) and with sediments 0.5 mm thick

From the analysis of ranges of the plates fluctuations presented in the figure 3 follows that sediments existence significantly changes her range of own fluctuations to plate surfaces in the range from 20 Hz to 10 kHz.

For increase in sensitivity of free fluctuations method for control of sediments it is offered to compare coefficients of *r* correlation of fluctuations ranges, determined by a formula:

$$r = \frac{\sum a_i a_{si} - \left(\sum a_i \sum a_{si}\right)/n}{\sqrt{\left(\sum a_i^2 - \left(\sum a_i\right)^2/n\right)\cdot\left(\sum a_{si}^2 - \left(\sum a_{si}\right)^2/n\right)}},$$

where n – the number of the compared frequencies in a range; a_i — amplitude of the checked range frequency; a_{si} – amplitude of a reference range frequency.

In fig. 4 correlation coefficients of "a pure plate" ranges and a plate with thickness of sediments of 5 mm are provided.

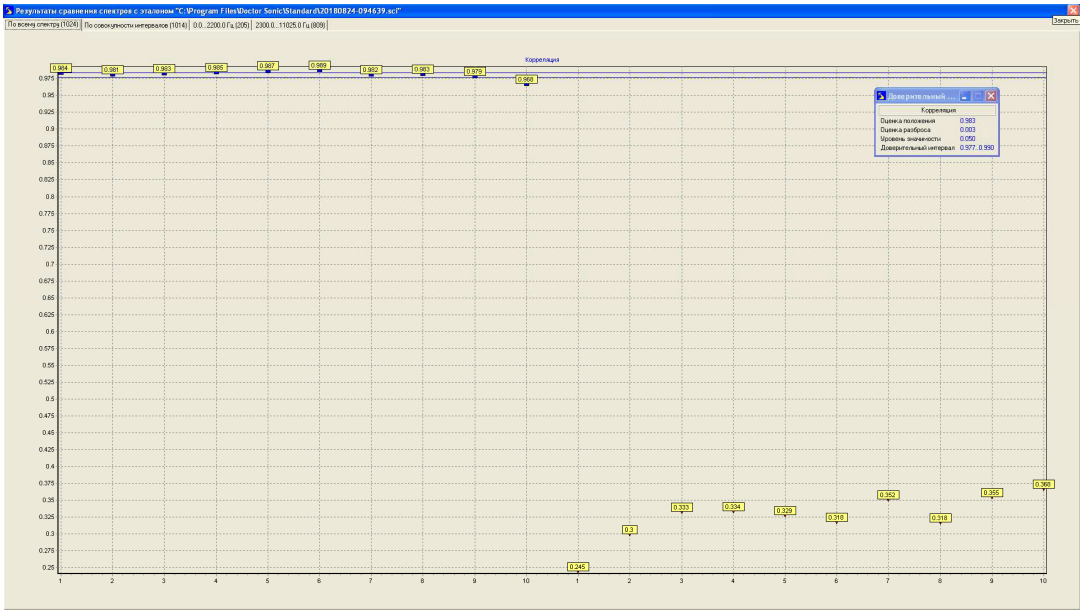

Fig. 4. Coefficients of ranges correlation of a "clean" plate and plate with sediments 0.5 mm thick

Process of record and the analysis of signals is realized in LabVIEW. The program of the analysis works as follows: signals are read out, on each signal the amplitude-frequency range is formed, ranges are compared on correlation coefficients, the received coefficients relating to one series of experiments are averaged, average coefficients are compared to border of a confidential interval.

For classification of riveted connection "suitable" or "defective" is used the approach characteristic of anomalies rejection procedures.

The analysis algorithm interprets set of the calculated values of correlation coefficient as a set of the measured values of some abstract parameter and applies the following procedure to this set of values: provision $\overline{p}$ assessment is calculated; assessment of dispersion of S as a median of absolute deviations concerning situation assessment is calculated; for the set significance value of α the confidential interval is under construction:

$$p \pm St\left(1 - \frac{\alpha}{2}, m - 2\right),$$

where – α Student's distribution quantile with freedom degrees.

In case of an exit of correlation coefficient of the compared range out of a confidential interval limits the conclusion about sediments existence on the surface becomes.

Conclusion

Existence of sediments on the surface of the heat-exchange equipment leads to the following negative consequences:

1. To decrease in the thermal productivity connected with falling of the actual coefficients of a heat transfer owing to growth of thermal resistance of heating surfaces.
2. To increase in hydraulic resistance result of reduction of their section through passage and roughness growth.
3. To loss of fuel and power of the heat-exchange equipment.

The negative effect of sediments formation can be minimized if to control of heat-exchange surfaces condition with a nondestructive control method.

Results of the conducted researches have shown that the method of free fluctuations allows to determine sediments thickness in the tenth shares of millimeter.

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